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Environmental Equality within the MBTA Bus System

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1.0 Introduction

Over the last 40 years, public transportation in the United States has contributed significantly to the reduction of harmful emissions and pollutants generated by the extensive use of personal vehicles and other forms of transportation. Currently, there are many benefits that accrue when people use public transportation instead of personal vehicles: these include a decrease in gasoline consumption (a savings of more than 855 million gallons each year), a reduction in the cost of energy bills for many individuals, and a reduction in the amount of air pollutants released into the environment (Shapiro, Hassett, & Arnold, 2002). Many of the emissions that have been reduced through increased use of public transportation, such as carbon dioxide and monoxide, nitrogen oxides, particulate matter, and volatile organic compounds, have direct impacts on climate change and public health. While these reductions constitute significant improvements compared to historical levels, there is still an opportunity to do more to make the environment a safer and cleaner place for all. Additionally, while it is obvious that public transit is better for environmental quality than vehicles in the private sector, it is not always a perfect system. For example, diesel fuel, which not only accounts for the largest portion of air pollutants and emissions generated by motor vehicles in many regions, which can produce many negative health effects, is still widely used by the bus fleets in cities around the country and the globe (Sydbom et al., 2001).

Because of this, a number of organizations continue to strive to see improvements made to the public transit systems in many cities across the United States. One such example is Alternatives for Community and Environment (ACE), an environmental justice community based in Roxbury, Massachusetts, within the city of Boston. ACE's mission, through its program

The T Rider's Union, is to create a more organized, cleaner and safer experience for public transit users within the greater Boston area. One of the organization's goals is to work together with the Massachusetts Bay Transportation Authority, or the MBTA, to improve the bus system within the city, which they claim is an important source of pollution and emissions due to the system's use of diesel fuel. By revising the system, the organization argues, improvements to the public health of transit users, along with reductions in harmful emissions linked to climate change, will be realized. Additionally, the Riders Union aims to provide environmental safety and equality to all riders and users of the transit system.

This project will examine the actual effects of harmful air pollutants and emissions on, first, the environment itself, and then on the general health of the public. It will also look at these factors within the context of environmental justice and racism, as well as climate justice. This will be done through a thorough literature review of relevant sources. A case study will then be completed examining several of the bus routes in the greater Boston area and mapping them against Census data to determine whether these routes tend to be located in areas that create inequalities for less privileged groups of people. Additionally, several routes will be examined against data for race, looking to see if a connection between where the routes run and the racial makeup of the area can be made. The hypothesis is that more bus stops will be found in areas that are poorer and more disadvantaged within Boston and its suburbs than in areas that are richer and more privileged, with the number of bus stops increasing as the median household income value decreases. This will create an injustice where those who are poor, being less able to afford environmentally safer and cleaner homes, will be exposed to the effects of increased vehicle idling, specifically the pollutants and emissions that are released from idling diesel buses, such as increased levels of black carbon, nitrogen dioxide, and fine particulate matter (PM), as they stop to let on and off passengers (Behrentz et al., 2005).

2.0 Background

A review of the scholarship on the negative effects of air pollution on both the environment and health will be done to show the hazards and risks associated with modern day increases in many air pollutants. This will lead to an examination of the specific effects of the emissions from diesel engines, which can be found in most of the buses used by mass transit systems in the United States. In addition, this paper will include a discussion of the importance of environmental justice, environmental racism, and climate justice, all of which are closely related. Finally, a study of the current sustainable endeavors of the Massachusetts Bay Transportation Authority will be completed to test the effectiveness of current initiatives of the state of Massachusetts and the city of Boston to provide a more sustainable, green, and healthy system for their riders.

2.1 Climate Justice

Climate change is one of the largest collective action issues of modern day (Jamieson, 2015). Determining the responsibility of climate change can be difficult to accomplish due to the complexity of the issue of climate change itself. Those who are responsible for the driving factors of the problem, and those who will feel the majority of the repercussions, can be hard to define because climate change is a global issue, and there are many actors who are involved, ranging from individual people to entire countries and their governments (Baskin, 2009). Additionally, moral issues arise when trying to determine what constitutes a morally wrong or morally right decision about who and what drives climate change. For example, should the negatives effects of climate change be considered injustices if those affected were responsible in some way for the problem itself? Environmental injustices are also generally different than other forms of injustices, such as those of racism and sexism, in that the battle to overcome the latter injustices can last for long periods of time before reaching a turning point, while those of an environmental nature are not indefinite, and eventually will reach a point where everyone is suffering equally due to the consequences of the changing climate.

When looking at the issue of climate change, there are several aspects that make solving it and determining responsibility unique. First there is the effect of modern technology (Jamieson, 2015). With the spread and the ease of obtaining technology in modern day, it is much easier to become a contributor to driving forward the effects of climate change. In the past, the simplicity of technologies, and the simplicity in which those technologies were powered, meant that one's footprint was smaller and the emissions that were produced were less costly on the global environment. For example, the consequences of riding a horse and buggy as transportation compared to driving a car to work are vastly different with completely different types and levels of emissions and pollutants produced and released. Then there is the spatial reach of climate change, meaning that harmful emissions released will not affect just the area where they originated (Jamieson, 2015). Since there are no limits or bounds restricting how these emissions spread, the carbon released from cars in rush hours traffic in Los Angeles will not only cause potential harm to that area but also on a global scale as the carbon seeps into the atmosphere, ocean, and other sinks. This can create a level of injustice where those who are not major producers of climate change drivers will be subject to the negative effects of climate change regardless. Similar to the limitless nature of the reach of climate change is lifespan of climate change. Rises in the levels of greenhouse gasses, as well as the effect of these gasses on rising global temperatures, are going to remain at elevated levels for years to come, even if production of greenhouse gasses were to cease today.

While there is currently much debate over where greenhouse gasses are originating from at such high levels, the issue will remain as one of global concern, due in part to the dependency on such gasses as CO_2 to drive the global economy. Many less developed and poorer countries are hesitant to commit to reductions that are being placed on their production of emissions, especially considering that many larger countries and producers of greenhouse gasses, such as the United States, have failed to commit to lowering their own emissions. Many of these less developed countries have a dependency on greenhouse gas producing fuels in order to drive their economy and their development. Additionally, these countries tend to not only create less pollutants and emissions in general, but are also at generally higher risks of the hazards of climate change due to a lack of the resources to abate the negative effects, such as more advanced technologies (Baskin, 2009; Jamieson, 2015).

2.2 Negative Environmental Effects Associated with Air Pollution

In recent years, the release of increasing amounts of many anthropogenic air pollutants and greenhouse gases into the atmosphere has been shown undeniably to be a driver of climate change. The Intergovernmental Panel on Climate Change (IPCC), using data collected as far back as 1901, has produced ample evidence supporting this connection. Greenhouse gas concentration have been steadily increasing since the 1950s, accompanied by an increase in the average global temperature, with the last thirty years generally believed to be the warmest period recorded in the last 1400 years (Stocker et al., 2013). The IPCC has a high degree of confidence that the rise in the global temperature over time is linked with the increase in the production of anthropogenic greenhouse gases. There are three drivers that are especially linked with the rapid increases in greenhouse gases and temperatures, the most influential being global, economic, and population growth. These three drivers are especially linked with the rapid increase in the production of carbon dioxide (CO_2); 78 percent of the CO_2 emissions created from 1970 to 2010 are tied to the increase in the combustion of fossil fuels and other types of industrial processes (Stocker et al., 2013). Since around the 1970s, concentrations of many greenhouse gases have risen dramatically as a consequence of human activity, with the levels of CO_2 rising by 40 percent over levels observed during pre-industrial revolution periods. Methane gas emissions have increased by 150 percent and nitrous oxide emissions by 20 percent over the same period (Stocker et al., 2013). These numbers not only exceed those recorded in recent human history, but also many levels recorded in ice core samples.

The drivers mentioned above that are fueling climate change are often measured in terms of radiative forcing (RF), with a positive RF reflecting warming surface temperatures and a negative RF reflecting cooling surface temperatures (Stocker et al., 2013). Since 1705, the total average cumulative RF value has been calculated to a positive value. The largest factor that is increasing RF values and, thus driving climate change, is the increase in the concentration of CO_2. For example, the total RF value for 2011 was measured at 2.29 watts per square meter, and of this, 1.68 watts per square meter can be attributed to the rise in CO_2.

Many natural systems across the globe have been impacted by the effects of climate change, and these impacts will continue unless mitigation in some form is undertaken soon. These impacts include an increased in the rate at which arctic ice is melting, shifts in the ranges of many species of plants and animals, the risk of many species of becoming extinct, ocean acidification, and increases in sea level (Stocker et al., 2013). However, climate change poses a danger not only to natural systems but also to human systems, creating environmental risks for many. These risks and hazards stem from the interactions between various climate-related hazards with the increasing vulnerability of human and natural systems. Additionally, climate change is predicted to have a negative effect on food security and water availability in many regions, with the impact on marine animals resulting in a decrease in foods that are staples in the diets in many coastal countries. In addition, primary grains, including rice and wheat, which serve as important components of the diets in many regions will also be impacted by the increasing global temperatures (Stocker et al., 2013).

These risks, along with the effects of air pollution on health discussed earlier, are not uniformly distributed among all members of society, however, with certain groups or individuals being at a greater risk. These groups are generally those that are economically disadvantaged, with those who can afford to live in safer and cleaner environments being able to avoid, or mitigate to some extent, the risks and hazards associated with climate change and air pollution. And inversely, poorer and more disadvantaged populations tend to have fewer options for housing, and are thus at a disadvantage when it comes to avoiding the risks associated with many environmental hazards. The idea of environmental justice came about in response to the inequalities associated with how various groups are exposed to environmental hazards and risks.

2.3 Impacts Associated with Diesel Engines

The diesel engine has become an increasingly popular means of powering vehicles not only in the United States, but also in other countries, particularly in much of Europe, with sales of diesel cars raising nearly 30 percent in Europe from 1980 to 2001 (Lloyd & Cackette, 2001). The use of diesel is only expected to grow in the near future. Diesel engines, while efficient, are not a clean or green source of power, as the process of burning diesel fuel leads to the production of many pollutants, such as fine particulate matter, nitrogen oxides, carbon monoxide, and black carbon or soot. Due to their dirty nature, regulations governing emissions from diesel engines have been strict since the initiation of the Clean Air Act in 1970, leading to significant reductions in pollutants released through the burning of diesel fuel. However, the burning of diesel still has an effect on the environment and human health.

When diesel fuel burns completely, the only byproducts are water and carbon dioxide. However, when diesel is burned in many motor vehicle engines, a complete burn is often not achieved, resulting in the formation of various other potentially harmful byproducts, such as solids, liquids, gasses, and various air pollutants (Sydbom et al., 2001). Of the air pollutants that can be produced from this process, some are types of nitrogen oxides and aldehydes, which are known to aggravate respiratory conditions and cause other health problems.

Studies have found that along roadways and in areas where there are frequently idling forms of transportation, such as in cities where buses stop often to pick up and drop passengers, the levels of particulate matter linked to diesel fuel were much higher than in areas that lacked the same level of idling vehicular traffic (Lloyd & Cackette, 2001). As was mentioned in previous sections detailing the effects of various air pollutants on the environment and human health, the burning of diesel fuel can lead to a variety of negative impacts, such as aggravation of the effects of climate change and increased exposure to carcinogens.

Dangers to exposure of diesel related exhaust are increased when buses are idling, such as at a bus stop. While most studies that have been done around bus idling have focused on school buses, due to the vulnerability of children to fine particulate matter, the results still apply to other forms of bus transportation, such as in public transit systems that run through urban areas. The hazards that are present in idling buses generally have to due with increased levels of pollutants becoming trapped within the vehicle itself as the concentrations are raised while the bus remains motionless. For example, higher concentrations of black carbon were found inside idling buses opposed to those that were moving (Wargo, Brown, Cullen, Addiss, & Alderman, 2002). Concentrations of black carbon, nitrogen dioxide, and PM2.5 were also found to be elevated at bus stops, with levels reaching as high as 2.5 times higher than areas where buses were idling for more limited times (Behrentz et al., 2005). Finally, increases in particulate matter of varying sizes (PM2.5s to PM10s) were found to be elevated after idling buses had opened their doors to let on and drop off passengers, with an increase in levels of PM2.5 increasing in particular (Kinsey, Williams, Dong & Logan, 2007). The pollutant that seems to be affected the most from bus idling is PM2.5

This is where the notion of environmental justice comes into play. Exposure to pollutants resulting from idling diesel buses may vary across communities as a function of their wealth or class. In particular, people living in poor and disadvantaged areas may be exposed to greater environmental risks and hazards due to the frequency at which diesel buses stop their communities, relative to more advantaged ones. Such greater exposure of poorer communities to environmental hazards would violate a fundamental need for environmental justice.

2.4 Environmental Justice

The concept of environmental justice is linked to early action against toxic waste and pollution being generated or stored in close proximity to the homes of certain minority groups or populations. More specifically, its roots can be traced to 1982 and Warren County, North Carolina, an area with a predominantly African American population (Chavis & Lee, 1987). Protests arose in Warren County after several hazardous waste landfill sites were sited there to contain harmful polychlorinated biphenyls (PCB). The concept of environmental justice has been defined in various ways by more than one group. However, its main components are as follows: many minority groups and communities are forced to suffer an unequal share of the negative effects of environmental hazards and risks, along with associated public health problems and a decline in overall quality of life (Agyeman, 2003). This can be attributed to a number of factors. For example, for the most part, higher income families have greater privilege and the means to ensure a greater degree of security for themselves when it comes to environmental quality and avoiding exposure to environmental risks and hazards. Poorer families have less choice when it comes to finding a safe home free of these risks and hazards; in fact they are often forced to live in close proximity to hazardous sites. Additionally, many of these minority groups and communities do not have proper access to the outlets that would allow them to take part in decision making and policy making processes. Regulatory agencies, such as the Environmental Protection Agency, have been found to afford many minority groups fewer rights and protections, especially when it comes to environmental and public health (Lavelle & Coyle, 1992). Non-white minority groups, in particular, are typically less represented in terms of environmental decision making, and often lack the proper advocates in public circles to assure that their rights and best interests are looked after (Ageyman, 2003).

Air pollution is among the hazards that can have the most serious impacts on minority groups, especially those that are at the highest risk of experiencing environmental inequalities. Minority groups and populations have been found to be more likely to live in areas where the chance of being exposed to environmental hazards and risks is higher than non-minority groups and populations (Ageyman, 2003). Adding insult to injury, most of the pollution and emissions to which minority groups are exposed are not generated by those groups, but rather by the wealthier members of society. However, it is the minority populations that are forced to deal with a majority of the burdens from the pollution and emissions, due to an inability to afford or have access to environmental safety.

Ideally, as a country or population becomes wealthier, the demand for a cleaner environment should increase, following the idea behind the environmental Kuznets curve. The theory behind the environmental Kuznets curve is that in less developed and developing countries, the levels of waste created and resources used can be maintained at a sustainable level (Stern, Common, & Barbier, 1996). But as economic development increases and as income rises, the levels of waste and resource depletion also increases. Eventually, economic development reaches a point where technological advances and the demand for environmental awareness bring about a drop in environmental damages to earlier levels (Stern, Common, & Barbier, 1996). The rise and fall of environmental impacts, therefore, forms an inverted bell-shaped curve. If this hypothesized link between the environmental degradation and economic development were true, then economic growth would be seen as a solution to increasing environmental damage, rather than the cause of an ongoing problem. However, this association has been shown to be flawed in many cases, leading to criticism of the kuznets curve model. As more and more research has been done, the environmental Kuznets curve has been found to be less reliable than was once believed. For example, the hypothesis at the heart of the curve assumes that the economy functions at a continuously sustainable level, and that any environmental damages that may occur would not affect the economy's growth (Stern, 2004). A study done by the World Bank as part of its World Development Report found that there have been times that the curve was applied correctly, but there were other instances where it did not fit the case (Mundial, 1992). The World Bank noted that while in some cases an increase in income may result in a decline in environmental damages, other potential solutions to reducing environmental degradation should not be ignored.

While income is not always a reliable predictor, certain other variables have been found to be good indicators of whether or not a country or region will have a more favorable level of environmental equality (Torras & Boyce, 1998). For example, countries with a higher literacy rate had, on average, a higher level of environmental quality; this was especially true in lower-income countries. Political rights and civil liberties functioned in a similar way to literacy rates, with countries having higher levels of these two variables experiencing greater environmental quality. Again, these correlations were found to be stronger in lower income countries than those with higher incomes. Finally, on average, as per capita income increased, environmental quality also tended to improve. However, this does not always mean that by raising the per capita income, improvements to the quality of the environment will improve. Not all parties always want to see a decrease in activities and procedures that results in the production of emissions and pollution, especially when these activities directly benefit those parties. In these cases, an increase in income results in an unequal distribution of wealth and risks and hazards.

There are cases where rising per capita income results in an increase in environmental quality. Often this comes about when sources of pollution and emissions are relocated to other countries or regions (Torras & Boyce, 1998). However, as was noted earlier in this section, actions like this often result in inequalities, as was the case in Warren County, North Carolina. These actions often unjustly impact racial minority groups, such as Hispanic and African American populations within the United States. Such inequalities reflect environmental racism, a construct closely related to that of environmental justice.

2.5 Environmental Racism

In many countries, including the United States, not all members of society are granted as many rights as others. While in the past in the United States, this unique distribution has been associated with the right to a quality education and the right to vote, today the right to be treated equally in terms of environmental health is widely discussed. Racial minorities experience an unequal exposure to the hazards and risks associated with emissions and pollution, with hazardous waste, in particular, being more likely to be concentrated in areas where racial communities are developed (Agyeman, 2003).

In many communities throughout the United States, people live in a close proximity to a hazardous waste site, increasing the odds that they will suffer from such serious health risks as cancer, nerve damage, birth defects, and contaminated water supplies (Faber & Krieg, 2002). A study done by the National Research Council in 1991 found that, at the time of the study, over 41 million people lived within four miles of a hazardous waste facility or site. These individuals suffered negative health issues, including an increase in the average mortality rate, far more frequently than those who lived in areas lacking a hazardous waste facility or site. A study done by Faber and Krieg in the Commonwealth of Massachusetts looked at the distribution of hazardous sites within the state and what sorts of communities developed around these sites. They found that low-income communities, which were categorized as those having a household income ranging between $0 to $29,999, were on average about four times more likely to be exposed to environmentally hazardous facilities and sites that all other communities (Faber & Krieg, 2002). High minority communities, which were categorized as those made up of 25 percent or greater of people of color, were almost nine times as likely to be exposed to environmental hazardous facilities and sites than low minority communities. In terms of environmental protection and equality when dealing with hazardous materials, minority communities and lower income communities were not equal to other communities, and were forced to deal with higher burdens.

An additional study carried out by the United Church of Christ found that three out of every five African Americans or Latino Americans lived in areas that were in close proximity to an abandoned or an illegal hazardous waste facility or site (Chavis & Lee, 1987). Additionally, areas that featured a hazardous waste facility or site had, on average, twice the number of minority populations. A follow up study done by the Church in 1994 found that minorities are 47 percent more likely to live in areas containing a hazardous waste facility or site than non-minorities (Goldman & Fitton, 1994). These waste and pollution sites, along with the high levels of various emissions mentioned in the earlier section focused on air pollutants and the environment, can have negative effects not only on the areas in which people live, but also with the lives and health of those that come into contact or close proximity to these hazards. The negative effects of these pollutants on human health will be examined further in the following section.

2.6 Negative Health Effects Associated with Air Pollution

While, overall, the levels of many pollutants have dropped significantly in recent years as laws and regulations have been put into place to monitor and lower harmful emissions, these pollutants continue to cause drastic health effects. Much of the pollution released into the air by various sources, including vehicles, can have negative impacts on human health, leading to increases in mortality rates, hospitalization rates, and in many different types of respiratory and cardiovascular diseases (Brunekreef & Holgate, 2002). From among the many sources of air pollution, a strong correlation has been found between pollution from vehicular traffic and several respiratory and cardiovascular diseases, leading to increased deaths from lung cancer and other respiratory related issues. In recent years, a large number of studies have been conducted on the relationship between human health and air pollution, with major publications coming from both the United States and a number of European countries. These studies have found that there are three main pollutants of particular concern: ozone, nitrogen dioxide, and fine particulate matter (Brunekreef & Holgate, 2002). These three air pollutants, with nitrogen dioxide falling under the broader category of nitrogen oxides, currently appear on the Environmental Protection

Agency's list of "criteria pollutants," which is a list consisting of six of the most common and also dangerous pollutants that can be found throughout the United States (Environmental Protection Agency, 2016d).

Ozone is a harmful greenhouse gas that can exist at ground level. Created by the reaction of sunlight on atmospheric hydrocarbons and nitrogen oxides, it can lead to harmful and potentially deadly respiratory conditions, especially in individuals who are already prone to such conditions like children, those with prior respiratory diseases, and the elderly (Environmental Protection Agency, 2016a).

Nitrogen dioxide generally is created through burning of fossil fuels, for example in automobiles (Brunekreef & Holgate, 2002). Nitrogen dioxide, like ozone, can have adverse effects in those who are already prone to respiratory conditions. Additionally, nitrogen dioxide can cause inflammatory conditions in the lungs of healthy people upon prolonged export to the pollutant, which can also lead to an increase in hospitalization of both healthy and unhealthy individuals (Environmental Protection Agency, 2016b). Levels of nitrogen dioxide have been found to be especially high around roadways and other areas of high vehicular traffic, as well as inside vehicles themselves. This puts those who are forced to drive or operate automobiles, or spend large amounts of time near roadways, at a higher risk for respiratory and cardiovascular disease and conditions linked to the effects of nitrogen dioxide. According to the EPA, around 16 percent of housing in the United States is located within 300 feet of a major roadway, where concentrations of nitrogen dioxide have been measured to be anywhere from 30 to 100 percent higher than concentrations in areas that are farther away from roadways (Environmental Protection Agency, 2016b). Additionally, according to findings by both the Air Pollution and

Health: A European Approach Studies and the National Mortality, Morbidity, and Air Pollution Studies, areas that are found to have higher than normal concentrations of nitrogen dioxide and also found to have higher than normal concentrations of dangerous particulate matter (Brunekreef & Holgate, 2002).

Fine particulate matter is a pollutant that poses risks to many members of the population, including children, the elderly, and those with already present medical conditions. Particulate matter comes in various forms (solid, liquid, or solid-liquid particles suspended in the air) and can be composed of any number of small pieces of matter, such as dust and metal particles, chemicals, and acids (Brunekreef & Holgate, 2002; Environmental Protection Agency, 2016c). The severity of the health issues related to particulate matter also depends on the size of the particles themselves, with smaller particles tending to be more dangerous as they have the ability to reach deeper the respiratory system and can remain in the body for longer periods of time (Katoshevski, Ruzal-Mendelevich, Hite, & Sher, 2011). The size of the particles that make up particulate matter can range anywhere from particles with diameters of 10 micrometers to those at the sub-micron levels, often called ultrafine particles. These particles are often grouped into three categories: PM10, which are those smaller than 10 micrometers in diameter; PM2.5, or those smaller than 2.5 micrometers in diameter; and ultrafine particles, which are those smaller than 100 nanometers. PM10 particles have been found to be able to reach the lower respiratory system, while PM2.5 particles have been found to reach the gas-exchange region of the lungs, and ultrafine particles have been found to penetrate the deepest parts of the lungs. The Air Pollution and Health: a European Approach (APHEA) found that as the concentration of particulate matter increases, both mortality rates and hospital admission rates increased. For every 10 microgram per cubic meter increase in PM10, the morality rate increased by 0.6 percent while the hospital admission rates for cases of asthma and chronic obstructive pulmonary disease increased by 1.0 percent for patients 65 years and older. Additionally, increases were also seen in admission rates for cardiovascular disease, with a 0.5 percent increase being recorded, and for the presence of black smoke (part of the emissions created from diesel engines), with a 1.1 percent increase being recorded (Brunekreef & Holgate, 2002). Similar results were found in a study done by the National Mortality, Morbidity, and Air Pollution Studies (NMMAPS) based in the United States. The NMMAPS found that, for every 10 microgram per cubic meter increase in PM10, a 0.5 percent increase in mortality was noted, with the hospital admission rate increasing by 1.5 percent for those afflicted by chronic obstructive pulmonary disease and 1.1 percent for those afflicted with cardiovascular disease (Brunekreef & Holgate, 2002). Additionally, researchers from both studies also speculated that there was a correlation between the increased exposure to harmful air pollutants over time and the shortening of overall lifespans. These studies, while only looking at the effects of PM10 on human health, show that there is clearly a pattern between the exposure to air pollutants and a negative impact on human health. It is most likely the case that if PM2.5 and ultrafine particles were looked at, the rates of mortality and hospital admissions would be much higher, considering that, for PM2.5, it has been found that around 83 percent of the particles end up reaching deep into the lungs (Sydbom et al., 2001).

Air pollution and the emissions associated with harmful greenhouse gases have a clear and evident effect on the health and well-being of those exposed to these harmful pollutants. This is just one of the deleterious effects of air pollution, and there are many other ways in which the abundance of emissions in the air is of concern. While there are still a variety of improvements that could be implemented to reduce the threat of pollutants and environmental hazards, a number of advances have been made in recent years to improve environmental safety. The state of Massachusetts, for example, has made significant strides in its approach to environmental protection and sustainability, which can be seen in some state initiatives concerning public transportation.

2.7 Recent Sustainable Efforts of the MBTA

In recent years, the Massachusetts Bay Transportation Authority, or the MBTA, has focused on establishing cleaner, more sustainable, and more efficient operations, with the goal of creating a smaller environmental footprint, reducing operating costs, and improving the health and livelihood of riders and customers. In May of 2012, the MBTA signed on with the American Public Transportation Association's (APTA) Sustainability Commitment Pledge, earning a level of "Gold" in the authority's first evaluation.

The MBTA is ranked as the fifth largest transportation system in the country, with nearly 400 million trips, totaling around 1.85 million passenger miles, per year (MBTA, 2014). With a mass transportation system this large, there is the potential for significant exposure to the ridership from pollutants and emissions created through the operations of the system, even as the region's carbon footprint is drastically reduced the more the system is used. Within the infrastructure of the MBTA, there are 1,193 miles of rail track with 270 stations located in Massachusetts and some parts of Rhode Island, with nearly 1.36 million trips per day occurring in 2012.

In 2009, data on several aspects of the MBTA operations began to be recorded in compliance with GreenDOT, an initiative between the MBTA and the Massachusetts Department of Transportation (MassDOT) created with the goal of reducing greenhouse gas emissions, promoting alternatives to traditional means of transportation (gasoline, diesel, etc.), and fostering smart growth development (MBTA, 2014). The data being tracked consists of water usage, greenhouse gas (GHG) emissions, greenhouse gas savings, energy use, recycling, ridership, non-MBTA vehicles miles traveled, and operating expenses, with 2009 serving as the baseline year for future comparisons and improvements in trends. The table below, showing improvements made between 2009 and 2012, is taken from the MBTA Sustainability Report from the spring of 2014:

	Baseline Year (2009)		**Goal for 2012**		**Results for 2012**	
Key Metric	**Unit**	**Value**	**% Change**	**Value**	**% Change**	**Value**
Water Usage	Gallons/UPT	0.39	-5%	0.371	-31%	0.27
GHG Emissions	Kg CO_2e/UPT	1.11	-10%	0.999	-23%	0.85
GHG Savings	Kg CO_2e/PSA	5.26	5%	5.523	10%	5.76
Energy Use	BTUs/UPT	14,404.01	-10%	12,963.609	-13%	12,546.46
Recycling	% of Total Waste	0.05	5%	0.053	12%	0.06
Ridership	UPT/PSA	75.51	2%	77.020	4%	78.28
Non-MBTA Vehicle Miles	VMT/PSA	11,339.77	-2%	11,112.975	-5%	10,789.64
Operating Expenses	$/UPT	3.33	-2%	3.263	-2%	3.25

Overall, the MBTA remains one of the largest users of energy in New England, consuming around 4.93 billion BTUs in 2009. But the authority was able to cut this usage down 13 percent by 2012 following their greener initiatives programs under GreenDOT. In terms of water usage, 142 million gallons were used in 2009, or 0.39 gallons per passenger trip. By 2012, overall water consumption had been cut by 25 percent, with per passenger water usage having dropped to 0.27 gallons. As for air quality, over 400 million kilograms of greenhouse gases were emitted in 2009, coming from nine carbon-based pollution sources, including electricity production, diesel, and jet fuels. By 2012 the MBTA had managed to reduce its emissions by 23.2 percent. Six primary modes of transportation are used by the transit system: bus, trolley, light rail, heavy rail, commuter rail, and harbor ferry (MBTA, 2014).

The MBTA also utilized the Health Impact Assessment done by the Metropolitan Area Planning Council to look at the effects of its transit system on the health of riders. It was determined that the more efficient and sustainable a mass transit system is, the better the mental and physical health of riders and the general population. In addition, fewer vehicular accidents were reported and more alternate forms of transportation were used, including bicycles and walking (MBTA, 2014).

2.8 Boston Demographics

Demographic information for the city of Boston will be taken from the U.S. Census (U.S. Census Bureau, 2016b). The city of Boston, with a size of 48.3 square miles, had a population of 655,884 in 2014, the latest year for which data is available, making it the twenty-fourth largest city in the United States. The racial makeup of Boston is 53.9 percent White, 24.4 percent African American, 0.4 percent American Indian and Alaskan Native, 8.9 percent Asian, and 17.5 percent Hispanic or Latino. In 2014, the median household income in Boston was $54,458, with 21.9 percent of the population living within the poverty range. For comparison, in 2014 the U.S.

Census estimated the average national median household income at $53,657, and the Massachusetts average median household income at $63,151.

3.0 Methodology

To examine the effects of public transit and, in particular, the effects of the bus system within the city and suburbs of Boston, two sources of data were relied on in the analysis of this case study. These sources were the MBTA's bus routes within the Boston area, taken from the authority's website, and median household income data taken from the U.S. Census. The income data were mapped against the bus routes to determine whether those with lower median household incomes are subject to higher risks associated with air pollution due to increased levels of bus traffic.

The source for the bus route was obtained through a search for "MBTA bus schedule" using Google, leading to the MBTA site, which supplied the schedule for all the bus routes within the city's transit system. This was the first result found through the search (MBTA, 2016). The median household income data was obtained using the Census Explorer Application, an interactive map feature that allows users to sort through various criteria on a map of the United States (U.S. Census Bureau, 2013). After these two sources of data were obtained, a method for determining which routes were to be used in the study was found.

The MBTA lists 168 active bus routes within its transit system, though not all these routes either lie within the Boston metro area or lead from a suburb into the city. The geographic outline of the Boston area, taken from Google Maps, was used to set the boundaries of the city and to decide whether a particular route entered the Boston area. These criteria were chosen to narrow down the list of routes to be included in the study were as follows: only weekday and inbound routes were included, as these are the routes used by commuters; only routes that run from a suburb of Boston and into a downtown area, where businesses operate, were included. After narrowing down the routes following these criteria, 28 routes were found to lead from the suburbs outside of the Boston area, into the downtown area where a majority of larger businesses operate. Those 28 routes were chosen to be examined against the median household income data taken from the Census Explorer site to determine whether or not lower income families are at a higher risk of the hazards of public transit, more specifically the risks associated with health complications and the risks associated with climate change, as a result of their location in relation to where buses frequent.

Each stop on the 28 routes were identified and located in the Census Explorer database. A record was made of the median household income for each of the stops. After every data point for each route was recorded and the raw data were collected, an analysis was done to determine whether there were differences in the number of stops as a function of the average median household income of communities. To test this, a repeated measures analysis of variance was conducted on the number of stops for each bus route. Finally, a second repeated measures analysis of variance was done on the data to determine whether or not the number of bus stops increased as the median household income value decreases.

The four routes that were selected to be examined against data on race were chosen based on which routes were good representations of both high and low median household income levels. To do this, the final percentages for all routes were looked at, and ones that lacked routes in either of the extremes were chosen. These final routes were then mapped against Census data taken for race to examine the percentages of White versus Non White populations (U.S. Census Bureau, 2016a).

4.0 Results

For the purpose of this case study, the breakdown of median household income used by the United States Census in its Census Explorer Application will be employed to sort the data points. The Census Explorer breaks down income into the following groups: less than $35,000; $35,000-$45,000; $45,000-$55,000; $55,000-$75,000, and greater than $75,000.

The total percentage of median household income in each category for the combined 28 routes examined in the study is shown below in Figure 1, with each wedge corresponding to the total percentage of bus stops that are found within each income range:

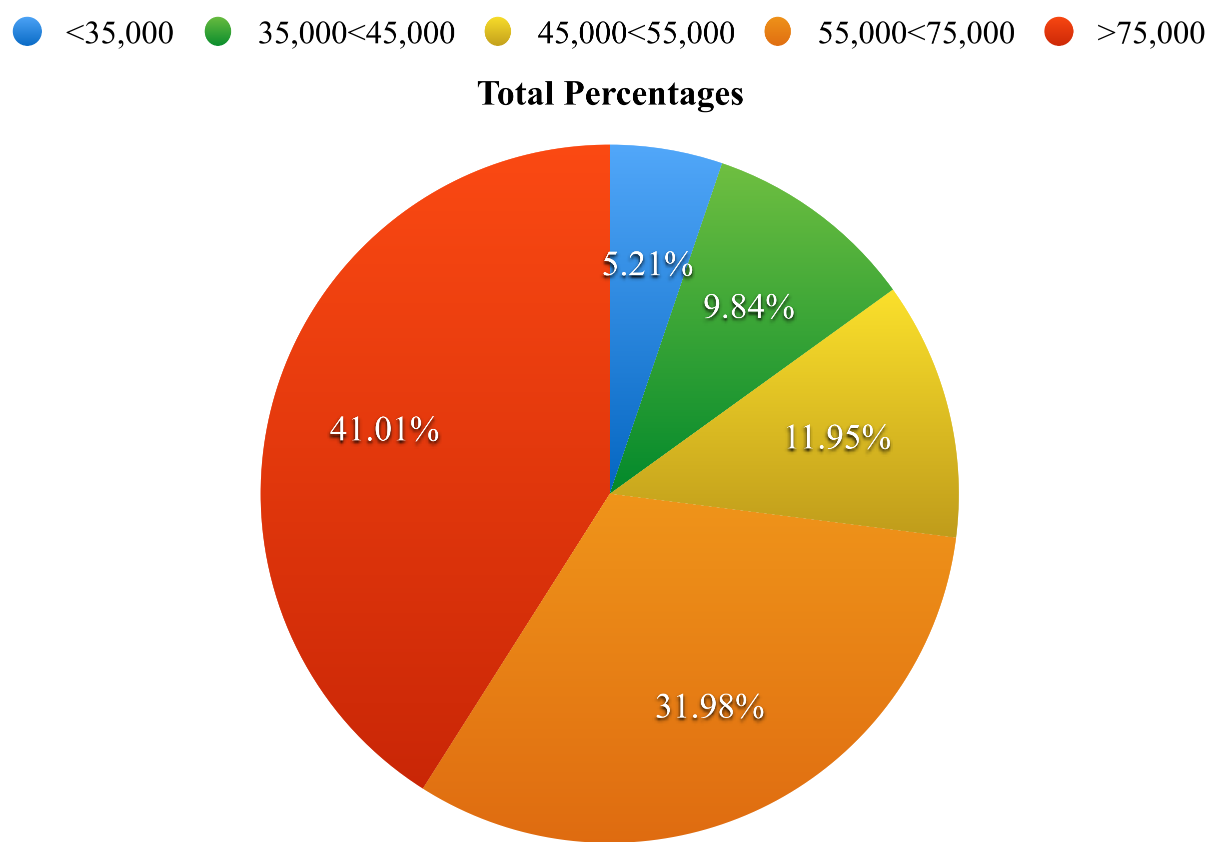

Figure 1

The largest category is median household income of $75,000 or higher (37.4 percent) and the smallest is median household income of $35,000 or lower (6.4 percent). About 30 percent of the population along the bus routes falls below the national median household income of $53,657. While some routes have higher percentages of people in the lower income categories, the majority are characterized by areas of higher median household incomes, with some routes, including 92 and 326, having no populations with incomes below $55,000. The map for route 92 (Assembly Sq. Mall Downtown via Sullivan Sq. Sta., Main St. & Haymarket Sta.) can be seen below in Figure 2:

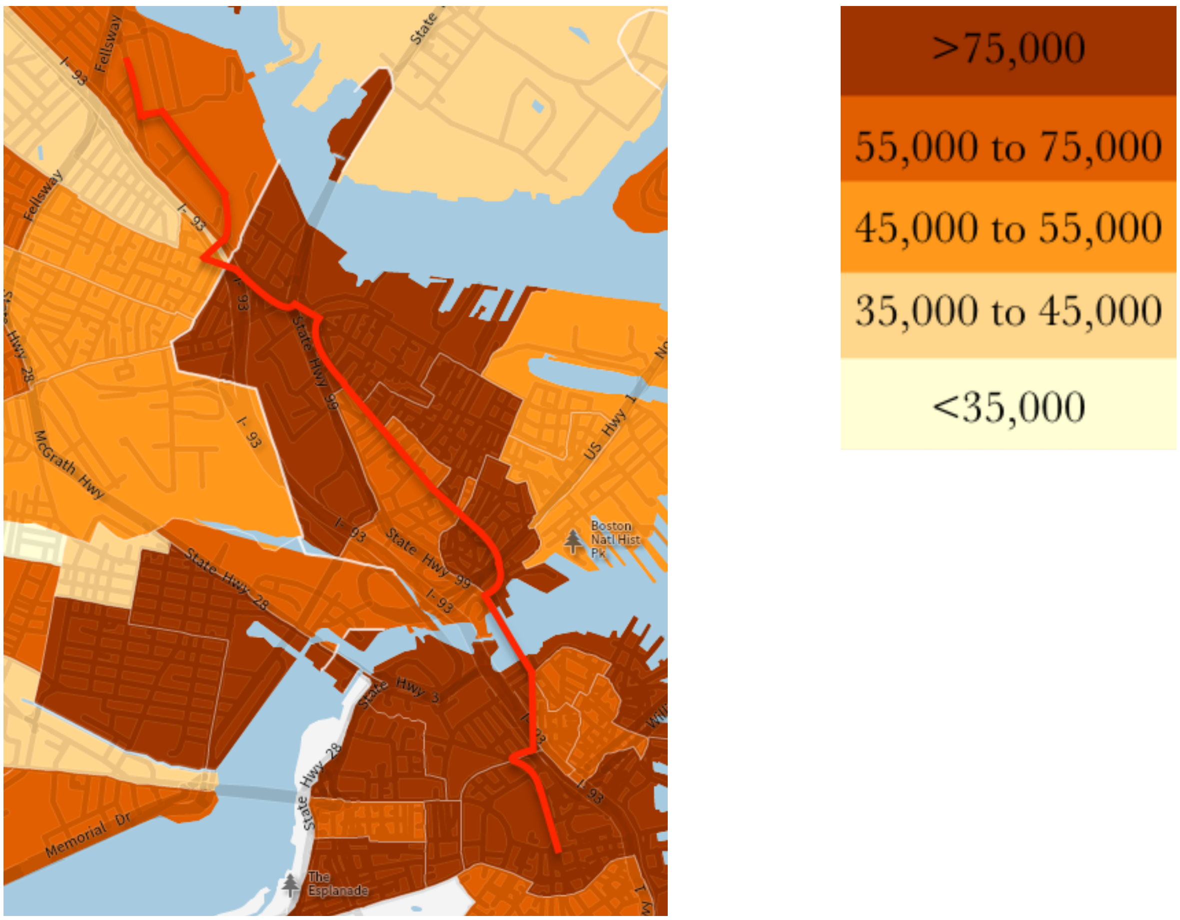

Figure 2

The map for route 326 (West Medford Haymarket Station via Playstead Rd., High St., Medford & I93) can be seen below in Figure 3:

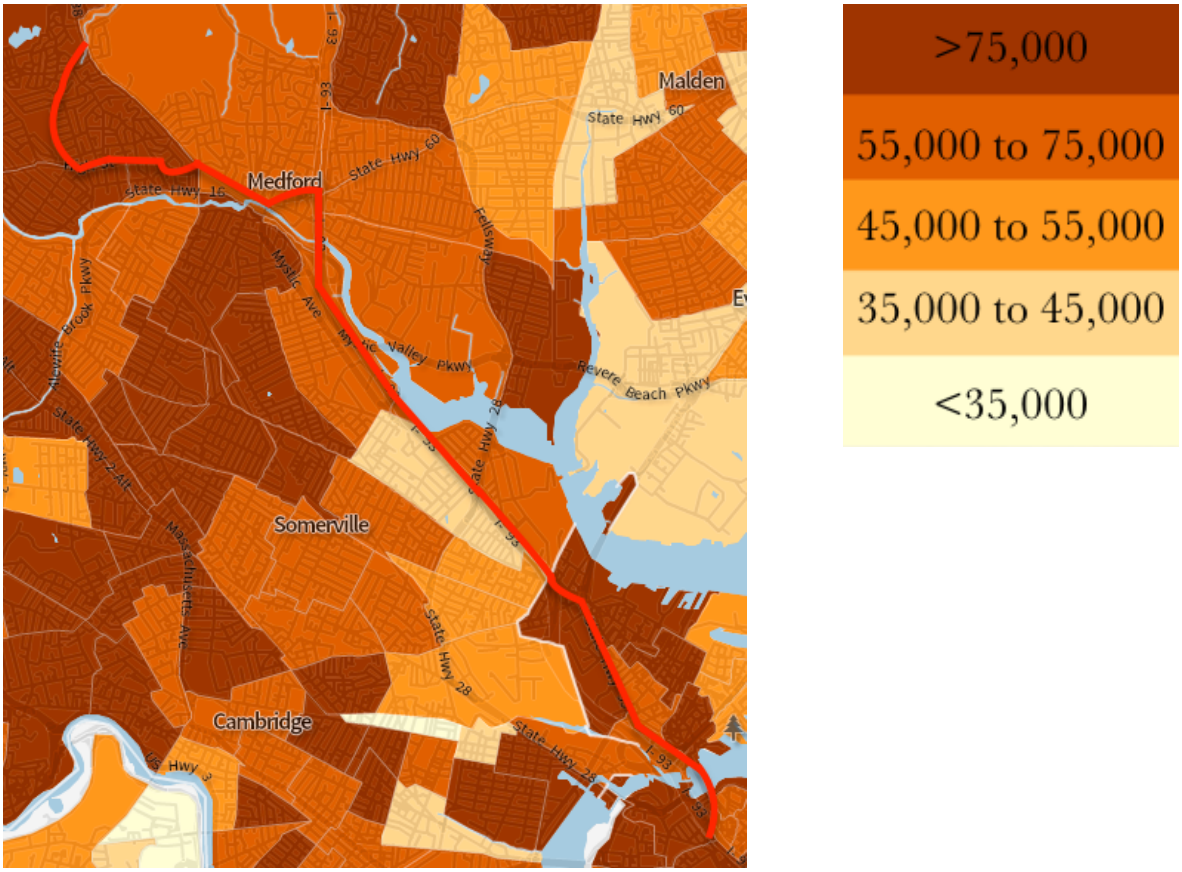

Figure 3

These routes lead from the Somerville area and the West Medford area, respectively. This concentration of higher incomes may be due, in part, to Boston having a high standard of living and high cost of living, especially in the suburbs surrounding the city where many people commute into the city, itself. Because of this the median household income in many of the suburbs is higher than in other cities, especially in areas in the north of Boston, such as Cambridge. From the maps it can be seen that the routes tend to move through higher income Census tracts.

However, some areas do tend to have lower median household incomes, such as routes that lead from communities like Revere, Quincy, and Chelsea. For example, routes 114 and 116 had much higher percentages of lower median household incomes. The map for route 114 (Bellingham Square Maverick Station) can be seen below in Figure 4:

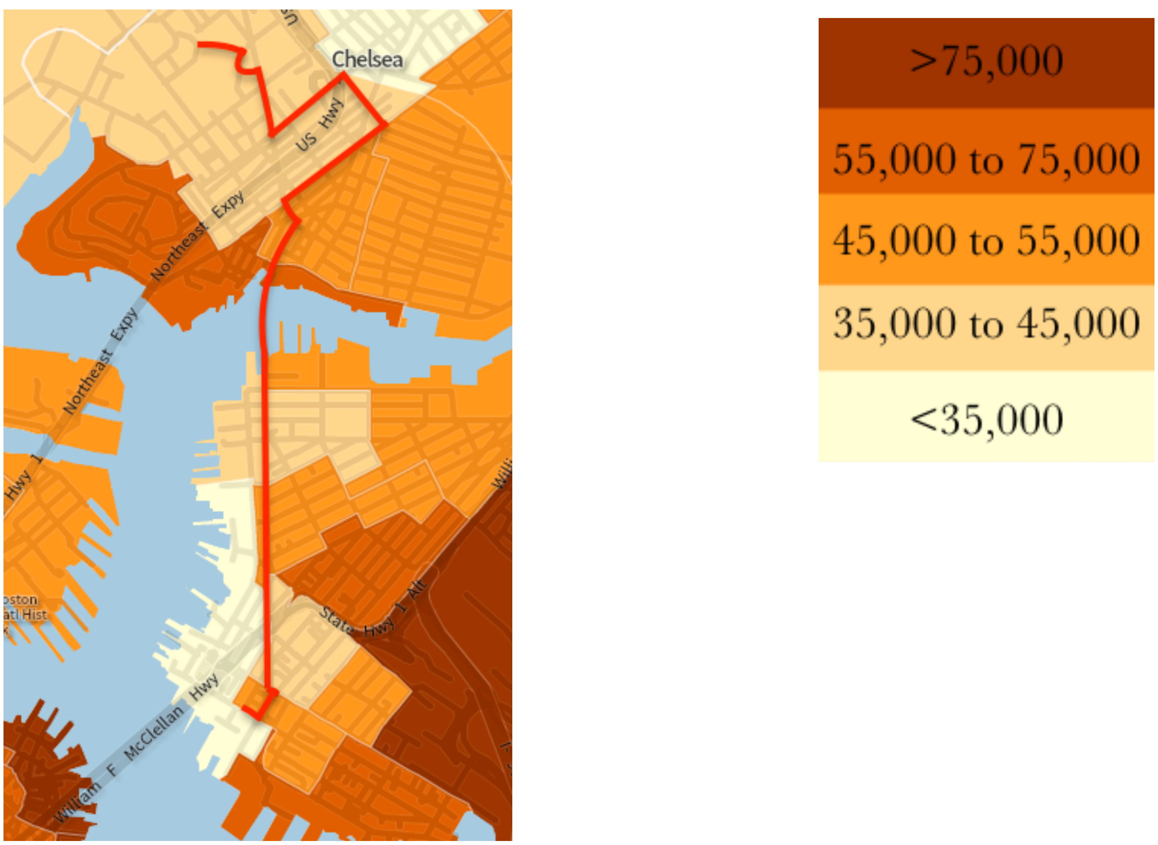

Figure 4

The map for route 116 (Wonderland Station Maverick Station via Revere Street) can be seen below in Figure 5:

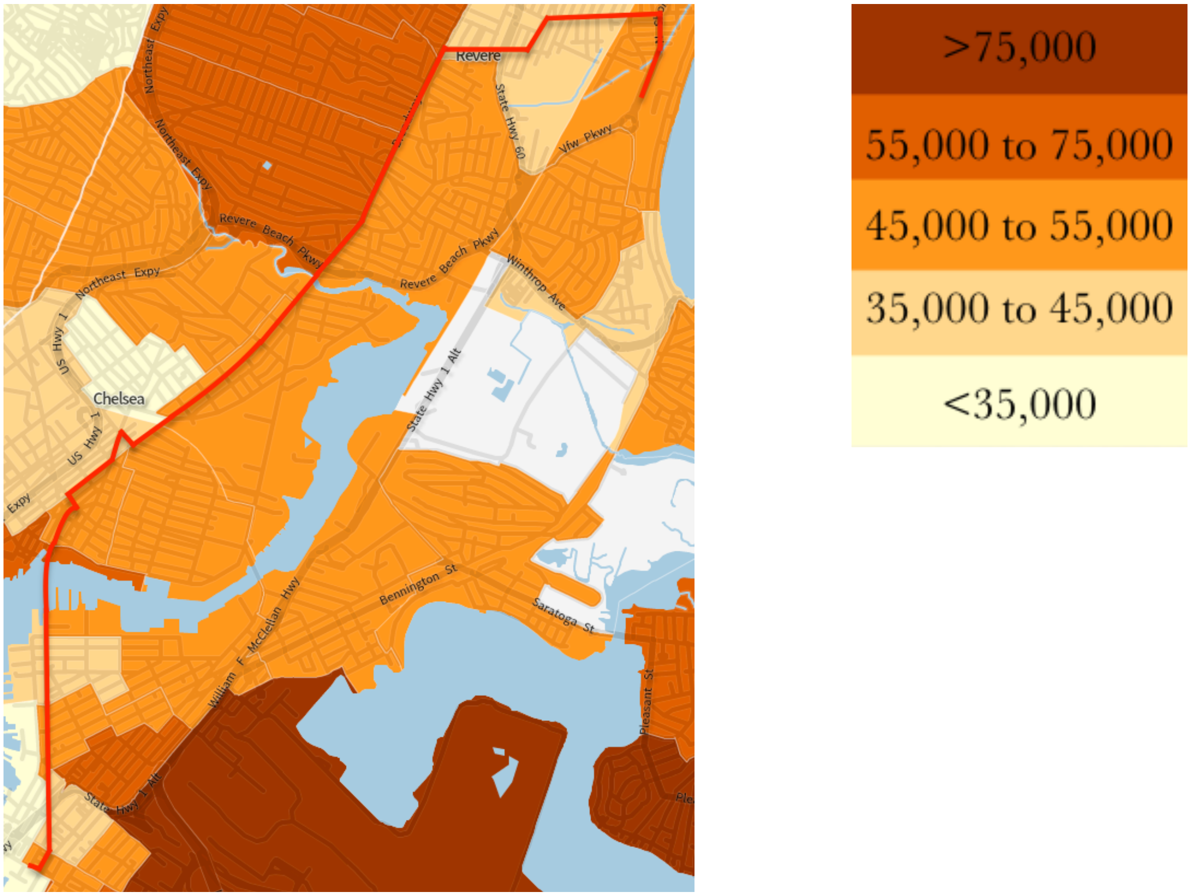

Figure 5

On these routes, which bring commuters into the city from the Chelsea area and the Revere area, nearly 50 percent of the population has median household incomes that fall below the national average. As noted above, this was not true for a majority of the routes, many of which ran through areas of much higher income, in some instances reaching above $100,000. The following map, using the two routes that were shown above, again follows the routes as they progress through the Boston area. Based on inspecting the results it seems that, of the routes leading to suburbs of Boston into the downtown area, a majority of bus stops are located within areas of higher median household incomes.

To test whether there would be differences in the number of bus stops as a function of income, a repeated measures analysis of variance was conducted on the data, with the five ranges of income treated as a repeated measure. Preliminary analyses indicated a lack of homogeneity among the variances of the differences in the means, so a Greenhouse-Geisser correction was applied to the analysis. The results revealed an effect of income, $F(2.18, 58.83) = 15.26$, $p < .001$. To test the hypothesis that the number of bus stops increased as the median household income value decreased, a second analysis of variance was conducted to look for a linear relation between the number of bus stops and income. The findings revealed that as the level of income in communities increases, the number of stops increase in a linear fashion, $F(1, 27) = 40.37$, $p < .001$. Therefore, the results do confirm that income level is associated with the number of bus stops, but in the opposite direction to that which had been predicted. Below, in Figure 6, the relation described above can be seen.

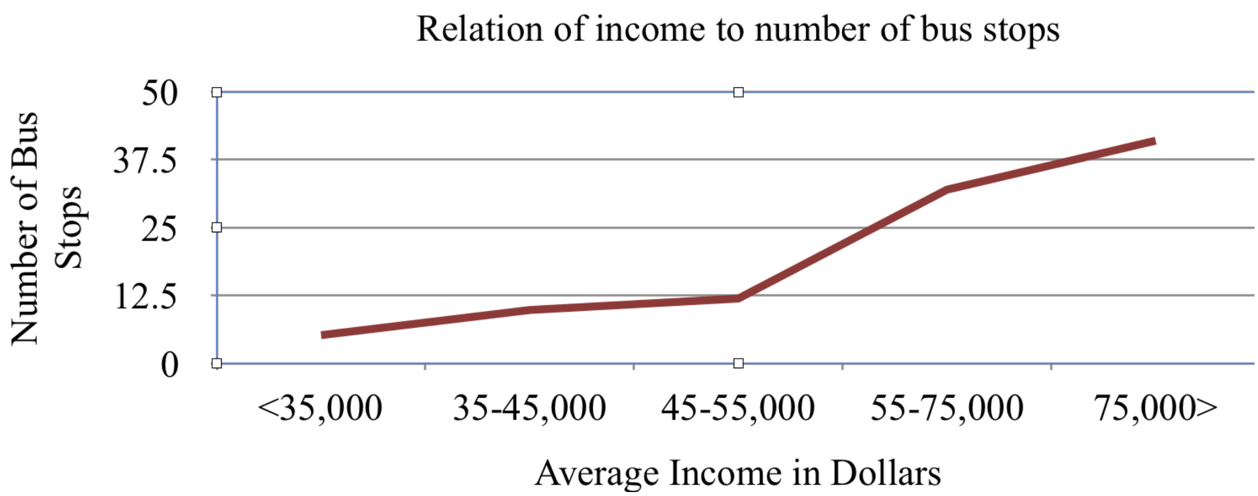

Figure 6

Finally, upon completing an analysis for racial data of the four selected routes used as examples, each chosen for either their strong correlation with high median household incomes (92 and 326) or low median household incomes (114 and 116), it was found that in the areas that consisted of higher incomes there was a higher percentage of White residents than Non White residents. In the two routes seen below in Figure 7, the percentages of Non Whites was extremely low compared to the percentage of White identifying residents. The tracts that these routes ran through had no values in the median household income ranges below $45,000.

Higher Median Household Income Routes

Route Number	**White**	**Non White**
92	76.32%	23.68%
326	84.53%	15.47%

Figure 7

In these two routes seen below in Figure 8, while the percentages of Non White residents did not exceed those of White, the percentage of Non White residents rose significantly, especially in the case of route 114, where the percentages nearly hit a 50/50 ratio.

Lower Median Household Income Routes

Route Number	**White**	**Non White**
114	51.57%	48.43%
116	59.8%	40.2%

Figure 8

5.0 Conclusions

The results of the study may not have been quite as predicted, with the majority of the MBTA bus stops on each route running through areas of higher rather than lower median household incomes.

Some factors created challenges in accurately recording the data. Many of the census tracts used roads as boundaries between individual tracts, creating many instances where a bus stop sits astride a boundary. Because of this, some data points may have been misplaced. Due to the nature of the online MBTA maps, these points were difficult to define precisely. This may have led to discrepancies in the results. Additionally, the MBTA has started to take certain pure diesel buses out of circulation, substituting hybrid buses that are more environmentally friendly. Since this study did not look at the type of bus that was being used on each route, it may be possible that routes that run through lower income areas are the ones that are still served by all-diesel buses, and therefore pose a greater risk to the health of those that use the transit system or live along the bus routes. Additional studies that better define the location of bus routes would most likely be needed to further explore in greater depth whether inequalities exist within the location of bus routes, or other forms of public transit, in regard to individuals exposures to the vehicles emissions. Using the results from this case study, it would seem that most bus routes that lead from the suburbs into the city of Boston are not primarily based within lower income areas. In fact, most of the routes lead through areas that are dominated by higher income populations, both when measured against the national and Massachusetts averages for median household income. This could, however represent a different type of injustice, one that goes beyond the scope of just public health. People who live in lower income suburbs and work within the city of Boston, based on the results from this study, may have a harder time finding transportation to get to their place of employment, with the MBTA bus system catering to those of higher incomes. There could be a number of reasons for this inequality, including the fact that those with higher incomes may be able to afford to pay higher prices for the bus services (a monthly bus pass currently costs a MBTA rider 50 dollars) or that those with higher incomes may have a greater voice in the community and merit a raised level of attention from the MBTA (MBTA, 2016). However, these inequalities move out of the scope of environmental inequalities and into the range of economical inequalities, since the poorer areas are not being exposed to the bus emissions, and into ranges of other inequalities having to deal with the financial status of an individual.

These findings do not prove that inequalities do not exist, and that minority groups do not suffer any increased environmental risks or hazards. Other case studies could be done to examine other forms of transportation, as this study focused on only buses and their effects. Many other forms of public transportation exist, and while in recent history the efficiency of transit has improved, leading to cleaner forms of transportation, more work can always be done.

Additionally, these results are for the city of Boston, which has in recent years prided itself on making large improvements to its public transit systems. Other cities in areas with less of a commitment to reducing the environmental impact of their transit systems may have a different situation, with a higher percentage of routes running through lower income areas, and lower income populations thus facing greater exposure to the pollution that diesel buses emit. Further studies could therefore look deeper into the public transit systems of other cities, and even other countries, to see whether the risks associated with air pollution are the same for lower income families and minorities, and those who can afford to live in cleaner areas. Studies could also be done comparing the results of this study around Boston to other geographical locations. One that might provide an interesting comparative case study is the city of Worcester, Massachusetts. Worcester lacks a train system and has a smaller dedicated taxi system than Boston, and therefore relies more on its bus system. Because of this, the bus routes of Worcester could affect a larger population that that of Boston, spreading more pollution that will reach more members of the population. Other studies in different areas of the country, or even different countries entirely, could also be down, especially in areas where the standard of living and the cost of living are lower than in Massachusetts and Boston.

Finally, based off of the results from the data comparing race against the bus routes, it would seem that in areas that are richer based off of the median household income, there is lower percentage of minorities represented. Therefore, using the results from the median household portion of this study, which showed that there is a linear relationship between income and bus routes where there is a higher percentage of routes running through richer areas, it would mean that there is a higher percentage of stops running in areas where there is a higher percentage of White residents. While the hypothesis of this study predicted that an injustice would be created when areas of lower incomes would be subjected to elevated levels of air pollutants due to a higher number of stops, which was ultimately proved false, a different injustice has been created, one in which areas that have higher percentages of minority populations have a limited access to the bus system provided through the MBTA. This could potentially make it more difficult for those minority groups to reach various parts of the city, such as areas in which they have jobs, areas that have hospitals, or areas that have other such amenities such as grocery stores.

Additionally, these populations could be even further burdened if they lack the means to own personal transportation which could be possible due to the expenses of cars in urban settings such as a city.

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Appendix

Median Household Income Percentages of Selected Bus Routes

Bus Route Number	<35,000	35,000<45,000	45,000<55,000	55,000<75,000	>75,000
15	16.7	20.8	33.3	23.6	5.6
39	11.3	1.9	7.5	47.2	32.1
57	30.4	4.3	0	26.1	39.1
92	0	0	5.6	33.3	61.1
111	21.1	15.2	27.3	30.3	6.1
114	5.6	72.2	22.2	0	0
116	2.8	41.7	41.7	13.9	0
117	2.9	34.3	54.3	5.7	2.9
325	0	6.3	0	81.3	12.5
326	0	0	0	26.3	73.7
352	0	0	0	0	100
354	0	0	0	67.5	32.5
426	18.4	6.1	6.1	32.7	36.7
428	0	0	0	52.5	47.5
434	4.5	6.1	25.8	25.8	37.9
448	0	13.6	1.5	25.8	59.1
449	0	15	1.7	5	78.3
450	6.7	20	28.3	30	15
459	14.5	18.1	27.7	32.5	7.2
501	0	0	26.7	33.3	40
502	0	0	0	14.3	85.7
503	0	0	25	25	50
504	11.1	0	0	33.3	55.6
505	0	0	0	48	52
553	0	0	0	48.9	51.1
554	0	0	0	19	81

	<35,000	35,000<45,000	45,000<55,000	55,000<75,000	>75,000
556	0	0	0	44.7	55.3
558	0	0	0	69.6	30.4